



Climate-Smart Potatoes

Abstract For a long time, Europe, North America and the former Soviet Union were the powerhouses of world potato growing. Since the 1960s, though, production in Asia, Africa and Latin America has more than quadrupled, and China and India between them now grow over one-third of the enormous 350 million tonne global potato harvest. Every tonne of raw chips has a carbon footprint of just under a tonne of greenhouse gas emissions. Each year in the UK, we discard some 320,000 tonnes that could have been eaten. This veritable mountain of dumped potatoes represents an annual climate penalty of well over 80,000 tonnes of greenhouse gas emissions. Drought is a major risk for many growers, as few in the UK use irrigation, and the viable area of rain-fed potatoes could shrink to 5 per cent of its current extent as droughts intensify in twenty-first-century Britain. Diseases such as late blight also pose a big threat for growers around the world. A combination of disease and drought-resistant varieties, along with irrigation, soil management and greater farm nutrient efficiency can deliver much greater resilience and more secure yields, while driving down emissions.

Keywords Scotland • Maris Piper • Irrigation • Blight • Scab • Drought • Waterlogging • Chips • French fries • Field hygiene • Seed potatoes • Cool storage • Bruising

For dinner it's a lip-smacking indulgence enjoyed in homes right across Britain: fish & chips. Voted as the nation's number one takeaway meal, a quarter of a billion chip shop meals are sold each year. Its joy has stayed with me since that very first newspaper-wrapped parcel of delight, eaten while huddled in a beach towel after a day of icy paddling in the North Sea. Britain's first chips reputedly went on sale in 1850s Yorkshire thanks to a lady called Granny Duce. They quickly became a hit here in Scotland too. Today over a third of Scots eat chips two or more times a week [1] and across the UK we chomp our way through one million tonnes of them each year [2].

The humble chip-yielding potato has come a long way from the high hills of the tropical Andes, where its wild ancestors were first domesticated over 5,000 years ago [3]. Introduced to Europe by the Spanish in the sixteenth century and helping power global population growth throughout the 18th and 19th centuries [4], it is now the world's fourth most important food crop after maize, wheat and rice.

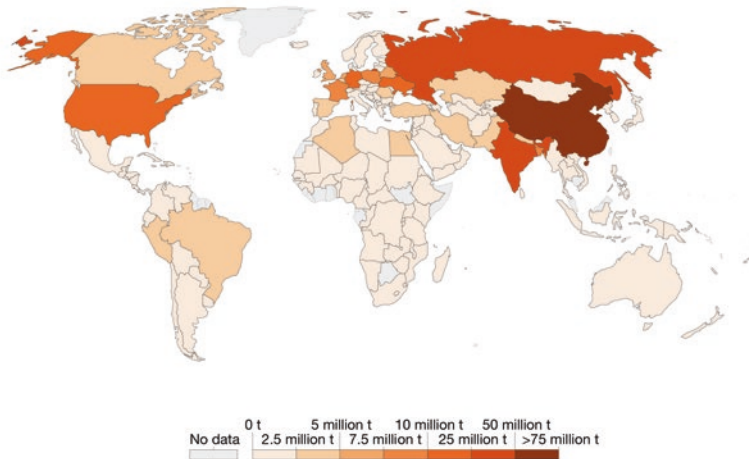
For a long time Europe, North America and the former Soviet Union were the warehouses of world potato growing. Since the 1960s though, love for growing and eating this versatile tuber has spread right around the world. Production in Asia, Africa and Latin America has more than quadrupled, and China and India between them now grow over one-third of the enormous 350 million tonne global potato harvest [5] (Fig. 12.1).

To fit the myriad climate envelopes and culinary preferences of a global audience, the potato plant has undergone centuries of selective breeding. The UK's Agriculture & Horticulture Development Board lists no fewer than 333 different varieties spanning the full spud-you-like alphabet from Accent to Zohar and including intriguing options like the Moulin Rouge—'unusual long tuber, good blemish resistance'—or the Picasso—'pink eyes and creamy flesh, resistant to common scab' [7]. Across in their native Andean home, work is ongoing to conserve and learn from the rich heritage of varieties and growing practices there [8].

In more temperate climates like that of Northern Europe, most potatoes enjoy a mean daily temperature of around 18 degrees Celsius, plus night-time temperatures that drop under 15 degrees Celsius to trigger the formation of the tubers. If it gets too cold (below 10 degrees Celsius) or too hot (above 30 degrees Celsius), tuber formation will slow or stop altogether. In the tropics, varieties are grown that are better able to cope with high temperatures and that can do well even with their shorter day-lengths compared to the long summer days of higher latitudes [3].

Potato production, 2014

Annual agricultural production of potatoes, measured in tonnes per year.



Source: UN Food and Agriculture Organization (FAO)

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Fig. 12.1 Global potato production in 2014 by country of origin (Source: Hannah Ritchie, Our World in Data) [6]. Available at: <https://ourworldindata.org/grapher/potato-production>

Potatoes like well-drained and aerated soil—in much of the world it is common to grow them in mounds or ridges to ensure their roots don't get waterlogged. But they are thirsty plants too. A shortage of water as potatoes form results in many being deformed and spindly. They may also get very scabby. So-called common scab is a problem for many farmers without access to irrigation. It often appears where the surface of the developing potato has dried out, producing unsightly brown pits and ridges [9]. Frequent watering during dry periods is the best scab-avoidance strategy, but leaving it too late and then dousing the fields can induce even bigger problems. If the plants become too water stressed and then receive lots of irrigation water, the potato tubers can split, opening them up to infection and leaving a nasty surprise when it comes to harvest in the form of a field of potatoes containing rotten black hearts [3].

Our own chip shop potatoes are good old Maris Piper, described as being 'high yielding, resistant to gangrene, and good for cooking and frying'. They are grown in the next county along from us and so have only

40 miles or so to travel from field to deep fat fryer. In Scotland it takes around three months from the planting of seed potatoes to harvest and, with willing weather, two or three crops a year are possible—the earlies, the main crop, and then perhaps a late planting to give potatoes in time for Christmas dinner. Seed potatoes—tubers grown specifically for re-planting and usually certified as disease free—are planted a few inches deep and begin sprouting up into daylight about a fortnight later. With the right combination of water, light and temperature, the plants soon generate multiple stems, spread their roots and begin to form new tubers. This is a crucial time for the size and quality of the eventual crop. Any brake on the development of the tubers, even short drought periods, means the final harvest will be smaller [10].

Within two months of planting the tubers should be filling out, a few weeks later the mature potato crop can be dug up. The relatively large weight and size of potatoes means damage during harvesting, cleaning and grading is a common problem. Scottish potato farmers have a specific guide on how to keep their harvest safer as it passes from soil to trailer, and from storage shed to delivery truck [11]. Evoking images of lab coats and large mallets, the guide even includes a damage league table, giving bruising and shatter risk scores for each of the main varieties.

Having survived the threats of field and farm machinery, our potatoes are almost ready for the fryer. The local fish and chip shop peels and chips the potatoes before deep frying in oil and handing them over wrapped in paper and smelling utterly delicious. In terms of carbon footprints, fresh potatoes are relatively light on their feet. They can rack up substantial emissions through the energy used to store them though, as they often need to be refrigerated in the summer months. Other emissions arise from the production of the seed potatoes, use of fertilisers and pesticides, and energy used for irrigation [12]. Overall, the growing, transport, storage and processing add up to just under tonne of greenhouse gas emissions for every tonne of raw chips that arrives at the takeaway [13] (or around 250 grams for a good mealtime portion [14]). But that's before they are cooked. Frying our chips, whether at home or in a shop, uses a large amount of oil and energy and represents the biggest component of a chip's life-cycle footprint. Using the average commercial deep fat fryer, the carbon footprint of our single portion of chips is doubled to around half a kilogram [13]—more if your local chippy uses palm oil, less if they use sunflower or rapeseed oil [15]. A sprinkle of salt and a dash of vinegar won't do much to change this, though if you have a penchant for smothering your chips in

ketchup, this will bump up the footprint by another 15 grams or so [16]. This may all look bad in the carbon stakes, but there is a big climate-saving grace for chips compared to most potatoes: we're more likely to eat them.

Any city high street on a Friday night or gull-circled seaside promenade can testify to the fact that we throw away chips. Compared to the huge mass of other potato meals that are wasted, however, our chips do pretty well. Each year in the UK, we discard over 700,000 tonnes of potatoes—equivalent to six million spuds every day and second only to bread as the nation's biggest food-bin filler. Much of this waste is in the form of peel and deemed 'possibly' avoidable, but some 320,000 tonnes are definitely avoidable. Not being used in time is again the most commonly cited reason for this waste—rare is the British grocery cupboard in which at least a couple of green and sprouting potatoes can't be found. Many are wasted because too much is cooked or served, with the remainder being wasted due to personal preference or accidents like burning the dinner [17]. This veritable mountain of dumped potatoes represents an annual climate penalty of well over 80,000 tonnes of greenhouse gas emissions.

The now hackneyed advice to cut such wastage by keeping track of what we have and only buying and cooking what we need still applies. Storing potatoes well—in dark, cool, well-ventilated conditions—can also prolong their usable lives and prevent them sprouting. Even where they have developed green patches or sprouts, these can be cut off and the rest used [18]. Cooking and serving only what is needed is easier said than done in most households, but the recipes for re-using leftover potatoes are legion [19]—leftover chips crammed between two slices of buttered bread have a special place in heaven.

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Britain is generally an ideal place to grow potatoes. We have the right temperatures, soils and annual rainfall to produce bumper crops. Scotland boasts some of the world's best seed potato producers and should be well placed to reap the spud-swelling benefits of a carbon dioxide-enriched atmosphere too. The future of our chip supper in the face of climate change would therefore seem secure, but recent severe weather events tell a different story.

The start of 2012 in the UK was a dry one. Potato farmers across the land were able to get onto their fields early and get the first crop sown into the dry soil, but then needed rain to help the young plants along. The

rains still didn't come. Our government held a drought summit to discuss the prolonged dry conditions affecting the southeast of the country. By March the area officially in drought had extended into northern England, with wild fires breaking out in Wales and Scotland [20]. The early potatoes were struggling. Drought conditions in the young vegetative stage hobble foliage and root growth, while at later stages it can mean deformed tubers and a plummet in the overall harvest [10]. Irrigation was used by some farmers, most just looked to the horizon for rain clouds.

Then, as April was drawing to a close, the skies across Britain darkened. In just a few days, some areas experienced more than three times their average rainfall for a whole month—homes were flooded, roads and rail lines cut. In Scotland the rain kept on coming. Soils that had initially been parched became sodden paddies, the uniform ridges of potato plants interspersed with long moats of standing water. Many crops of earlies simply could not be harvested. The drought conditions had already weakened the plants, now the moist air and sodden soils were the cue for damp-loving potato diseases to take their toll. Infection by black leg—a bacterial disease that dissolves the cell walls of plants—hit highs not seen in Scotland for 20 years [21]. Then came a surge in the potato's most infamous foe of all: blight.

Late blight is a highly destructive disease caused by a fungus called *Phytophthora infestans*. It first arrived on the shores of an unsuspecting Europe in the 1840s. With alarming speed it spread through the continent's farms, its tell-tale lesions on foliage and wet and dry rot of the tubers soon appearing in Ireland. The impact was devastating. Waves of the disease burned through Irish potato harvests for year after starving year. It putrefied the main food source for more than one-third of the population. An estimated 1 million people died of starvation and epidemic disease in the space of just five years. Another two million quit Ireland for foreign—and hopefully less blighted—shores like the Americas [22].

Blight likes wet conditions, with high humidity and temperatures of 15 to 20 degrees Celsius being optimal for it to grow and release its many millions of infectious spores. These spores can swim in the thin films of water on leaf surfaces [23]—they have whiplash type flagella to propel them—and once they've found their target, they quickly encyst and germinate. Each sends out a germ tube that penetrates the plant tissues. Within a few days lesions begin to appear on the infected plant's leaves or stems. Initially these are small and irregular, then expanding to form a circle of brown dead tissue. During warm and moist periods, whole plants

(indeed whole fields of plants) can be blighted. Infected fields carry a distinctive dank and mildewy smell—the first warning whiff on the breeze of the putrid inedible mess that is being made of the tubers underground.

Soon after a lesion appears, the new fungus is itself ready to produce spores. A single lesion may produce 100,000 sporangia—protective capsule structures containing the spores that can themselves be swept up into the wind and travel several kilometres to infect potato pastures new [24]. Infected material, such as tubers kept in storage or left in the ground, provide overwinter disease banks, while the international shipping of seed potatoes provides it with a readymade global distribution network.

Almost all potato areas across Asia, Africa, Europe and the Americas have blight now or have had it in the recent past. Blight-free areas tend to be those that are cold or hot enough to kill it off—those at very high or low latitudes and altitudes. As of 2008 the global cost of potato blight was estimated at over \$6 billion a year. A warmer future is predicted to further increase risks in cooler areas and the earlier-onset of outbreaks [25]. Nearly two centuries on from the Irish Famine, late blight still poses a major threat to the food security of millions.

Too much rain then, even for the thirsty potato plant, can pose a threat. As such, the climate change projections for eastern Scotland make for worrying reading for growers. By the middle of the century, winter rainfall may increase by one-fifth [26], with that rain falling in ever more intense downpours that risk stripping the soils of nutrients and making planting of the early potato crop an exercise in professional mud management.

Future summers are set to go in the opposite direction, becoming up to one-third drier by the 2050s, alongside a hike in maximum daily temperatures of over 4 degrees Celsius. A taste of this dusty future was delivered in 2018 when, after a late spring, the UK experienced one of its hottest and driest summers on record. In July temperatures peaked at over 35 degrees Celsius in the south and wildfires became a major issue over in Wales. Lightning storms left 30,000 homes without power, with a mini-tornado and hailstones the size of £1 coins reported. When any rain did fall, it came in torrential downpours, leaving roads blocked and drain covers blasted out of the ground [27]. On the potato farms, the combination of high temperatures and little rainfall was stunting plant growth and shrivelling the tubers. Evaporation rates from the soils in Scotland were equivalent to those a thousand miles south in central France, but only around one-third of the Scottish farmers had irrigation systems in place [28]. Across northwest Europe the harvest fell by around

one-fifth, with many farmers reporting poorer sizes and quality [29]. Even the UK's popular press were alarmed, warning that chips would be an inch shorter due to the droughts [30].

For our own Maris Pipers, the impacts of climate change by 2050 are a distinctly mixed hessian bag. Higher carbon dioxide concentrations in the atmosphere and longer growing seasons might mean a slight boost in yields [31]—about 5 per cent under current practices or up to 15 per cent if all their higher demands for water and fertilisers are met. Supplying enough water is the key. The use of irrigation water would likely need to rise by a third, and this future climate of hotter, drier summers would mean water demands exceed current supplies for almost half of the farms [32]. The area suitable for traditional rain-fed potato growing—such as eastern Scotland—could shrivel to a scabby one-twentieth of its current extent as droughtiness intensifies [33]. Without irrigation, many of these potato farms would cease to be.

Globally the climate scenarios for potatoes give a similarly mixed picture of some winners and potentially huge numbers of losers. In northern India and across the highlands of South America, Africa and Asia, yields could see an uptick of one-fifth or more as plants benefit from more carbon dioxide [25]. But in large regions of North America and Eastern Europe, potato production is set to fall precipitously. As drought, disease and pest damage intensifies, some areas could see more than half their harvest wiped away. Other regions, including many farms in the northeastern US, the Caribbean and southwest Russia, risk being obliterated from the world potato-growing map altogether. Overall, a small drop in worldwide yield is predicted by the 2050s, rising to a reduction of up to one quarter towards the end of the century [34]. If realised, this would put a major tuber-shaped dent in global food security.

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The projected impacts of climate change on potatoes may be dire for many, but most scenarios assume no change in which varieties the farmers will choose and how they will grow them. In reality, farmers will adapt to the changes they see—called autonomous adaptation—by switching varieties or altering their planting and harvesting dates.

For the spectre of drought that hangs over many farms, the installation of irrigation is an obvious route towards greater resilience. There are costs in terms of the equipment, the energy used for water pumping and the additional stress this could put on wider water demand, but if it can be

coupled with on-farm rainfall capture and storage, it has the potential to be lower carbon, avoid major losses in yields and more than outweigh the upfront costs of installation. Recent years have seen a surge in the creation of winter-filled reservoirs on farms in England [31]. These have the dual advantage of helping to manage the impacts of more intense rainfall events and their soil-scouring risks, while banking the excess water for the hotter, drier summer months ahead.

As demand for irrigation water spirals upwards, more efficient use of it can also help ensure that on-farm supplies meet the thirsty needs of the potato crop without hiking up carbon emissions. Careful scheduling of watering alongside good soil monitoring and weather forecasting—to best meet the changing needs of the plants as they develop—pay big dividends. Equipment like automated drip or trickle irrigation allows growers to deliver water to exactly where and when it is needed, and to avoid some of the wastage and uneven supply issues common to rain guns and sprinklers [35]. By incorporating more organic material like composts and green manures [36], the soils themselves can be managed to increase their fertility, workability and how much moisture they hold. Likewise, encouraging the plants to develop deeper roots—by providing irrigation in large sustained drenchings rather than lots of small sprinklings—means that drying out of surface soils during a drought will do less damage [37].

For farmers without access to irrigation water, switching to more drought-resistant varieties can bring much-needed resilience as weather extremes become even more extreme. Desiree potatoes, for example, are able to respond to dry periods by diverting water and resources to their roots and tubers instead of the shoots and leaves—banking their reserves for a rainy day. Our own Maris Pipers are already a pretty good choice in terms of their ability to endure limited drought periods and then make good use of any rainfall later in the growing season. Others, like the UK's widely grown Lady Rosetta, have a much tighter growth window, and so, even a short-lived drought can be very destructive [31].

With wetter winters, timing the planting and harvesting to avoid saturated soils, together with the use of lighter and broader-wheeled machinery, can reduce soil damage and compaction. Well-maintained and operated harvesting, storage and transport systems will also cut losses due to damage and spoilage [11, 38]. For pests and diseases like late blight, improved field hygiene and use of resistant varieties can prevent serious outbreaks [39]. Wherever such strategies increase climate resilience and productivity, they are likely to give indirect emissions savings—each additional potato that makes it through the minefields of blight and

drought avoids the need to grow a replacement. By using farm nutrient budgeting and greater precision in the quantity, timing and placement of fertilisers, direct emissions can be radically reduced too, while some potato varieties also produce copious amounts of shoots and leaves that can then be incorporated into the soil to boost its carbon content.

Around the world, the climate-smart options that will work best for a particular farm will depend on its local circumstances. Growing a super-resilient low carbon potato that nobody wants to eat is worse than pointless. Instead, working with growers to identify climate risks and opportunities in the context of the myriad other demands they face is more likely to deliver lasting benefits [40]. For some this will mean a transition away from potato growing and diversification into new crops. For others, it will mean an increase in fertiliser, water and pesticide use—boosting resilience and productivity at the expense of emission reductions. But where any such hike in inputs is able to induce an even bigger boost in yields, then the climate impact of producing each individual potato (the emissions intensity) is still reduced.

For the potato farmers of Ethiopia's Rift Valley, just such increased intensification has been suggested, with a need for irrigation, improved varieties, and increased availability of fertilisers and pesticides all being highlighted [39]. Access to training, technology and finance is, as is so often the case, a major barrier. In India, the successful introduction of new heat-tolerant and disease-resistant potato varieties has been helped by direct participation of farmers in what is selected, and where and how it is used. With malnutrition a big and still-growing problem in India [41], the provision of biofortified potato plants (ones that produce crops especially enriched in key nutrients) also has huge potential—more than half of children in India are currently at risk of vitamin A deficiency and its resulting health problems, including childhood blindness [42].

The West Lothian chip buttie that we eat in years to come may be smaller and the prices higher but, for millions around the world, failure to realise a climate-smart future for the humble spud may mean there is no supper at all.

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